Critical Thinking: Science, Models, & Systems

tutorial by Paul Rich

Outline

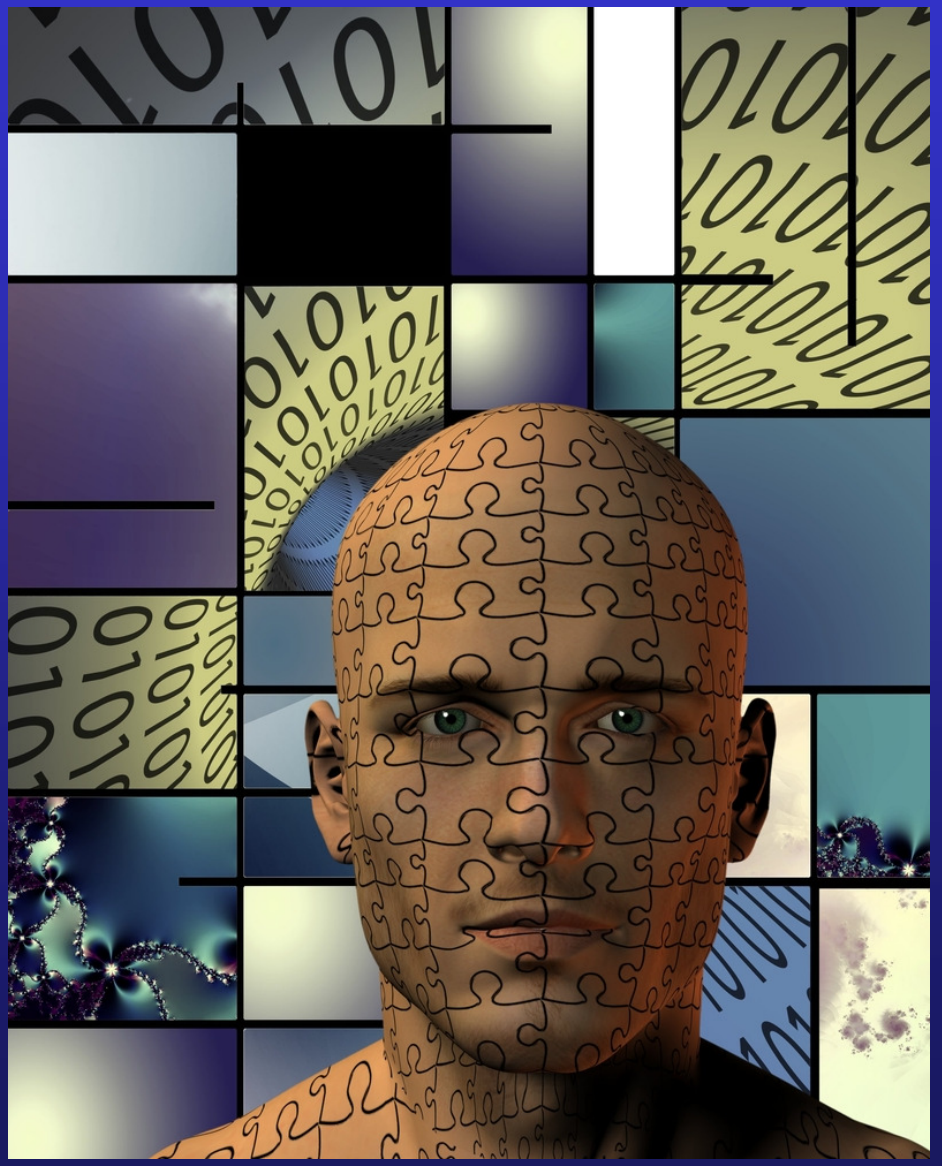
1. Science & Technology
- What is science?
- What is technology?
- scientific process

2. Systems
- What is a system?
- inputs, throughputs, & outputs
- feedback loops
- behavior of complex systems

1. Science & Technology

Science
pursuit of knowledge about how the world works

Technology
creation of new products & processes intended to improve survival, comfort, or quality of life



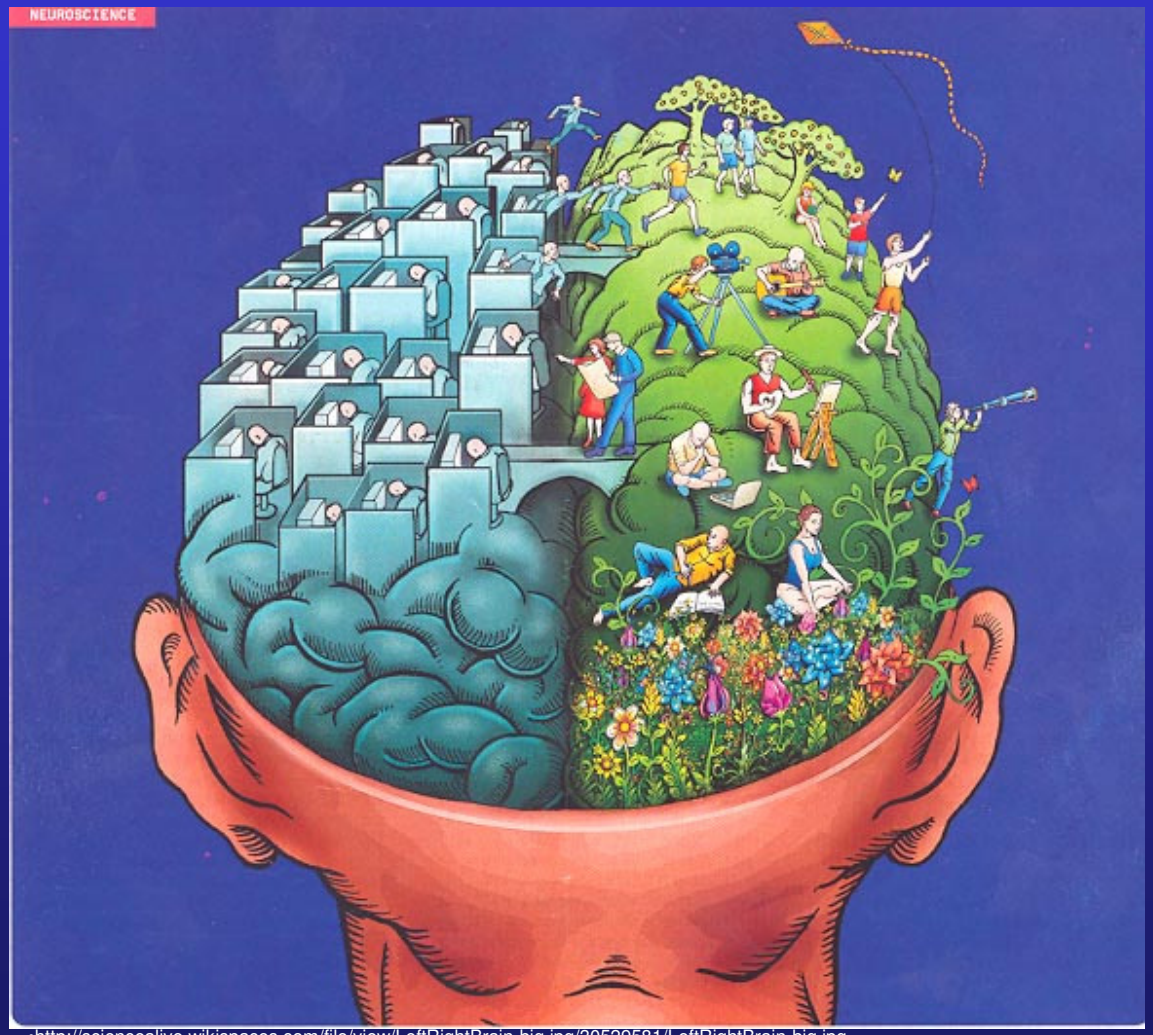
•http://www.stu.edu/images/sciencetechnology/new/science%20fiction.jpg

Basic Assumptions about Science

•http://www.mahrouyeh.com/uploads/img0812.jpg

1) There is order in the universe.

Basic Assumptions about Science



•http://sciencealive.wikispaces.com/file/view/LeftRightBrain-big.jpg/30529581/LeftRightBrain-big.jpg

2) The human mind is capable of comprehending this order.

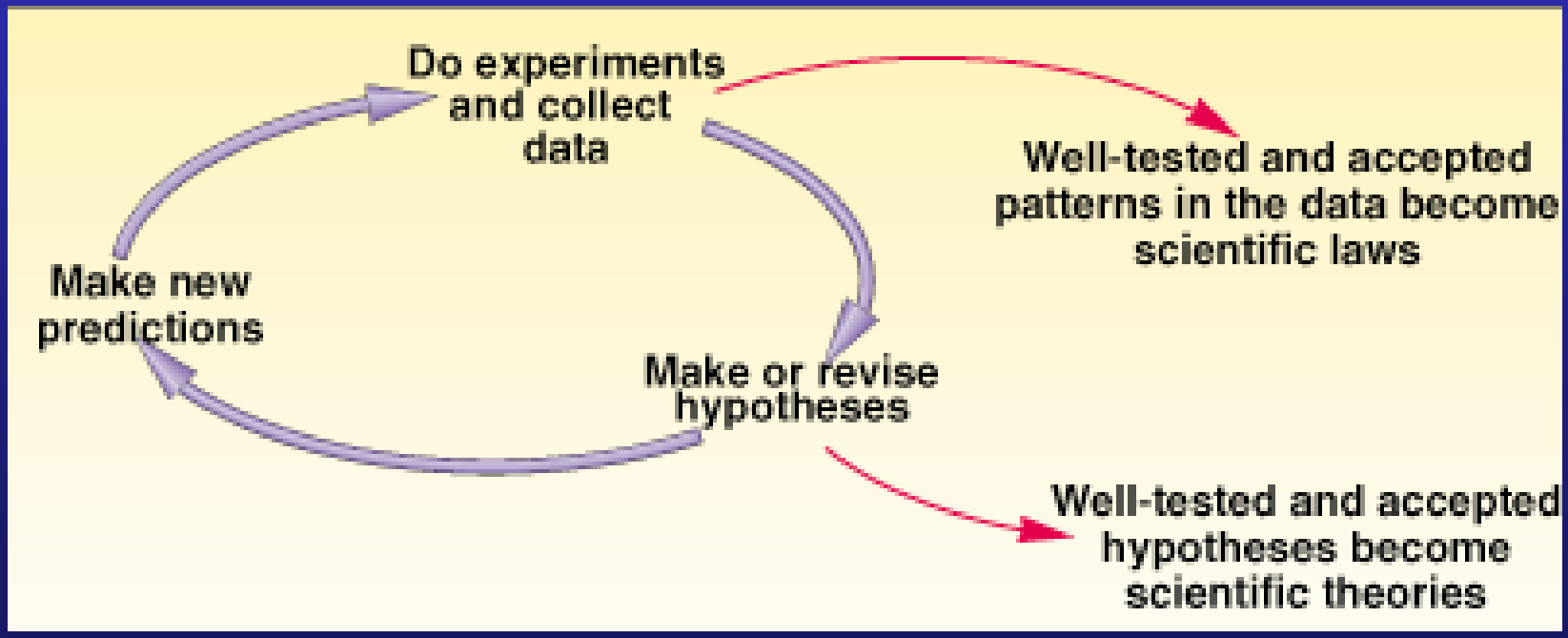
Basic Assumptions about Science

•http://ssrsbstaff.ednet.ns.ca/jcroft2/images/Sept19%20Deb%203E%20009.jpg

3) If conditions are the same the results will be the same.

Scientific Process

- **hypotheses** proposed to explain observed patterns
- critical tests or **experiments** conducted
- a hypothesis supported by a great deal of evidence becomes a **scientific theory**



Hypotheses & Science

Hypothesis
a tentative explanation; a testable statement

some characteristics:

- good hypotheses are falsifiable, can potentially be shown to be incorrect or false
- science proceeds by rejection of hypotheses
- no such thing as final proof

Scientific Laws & Theories

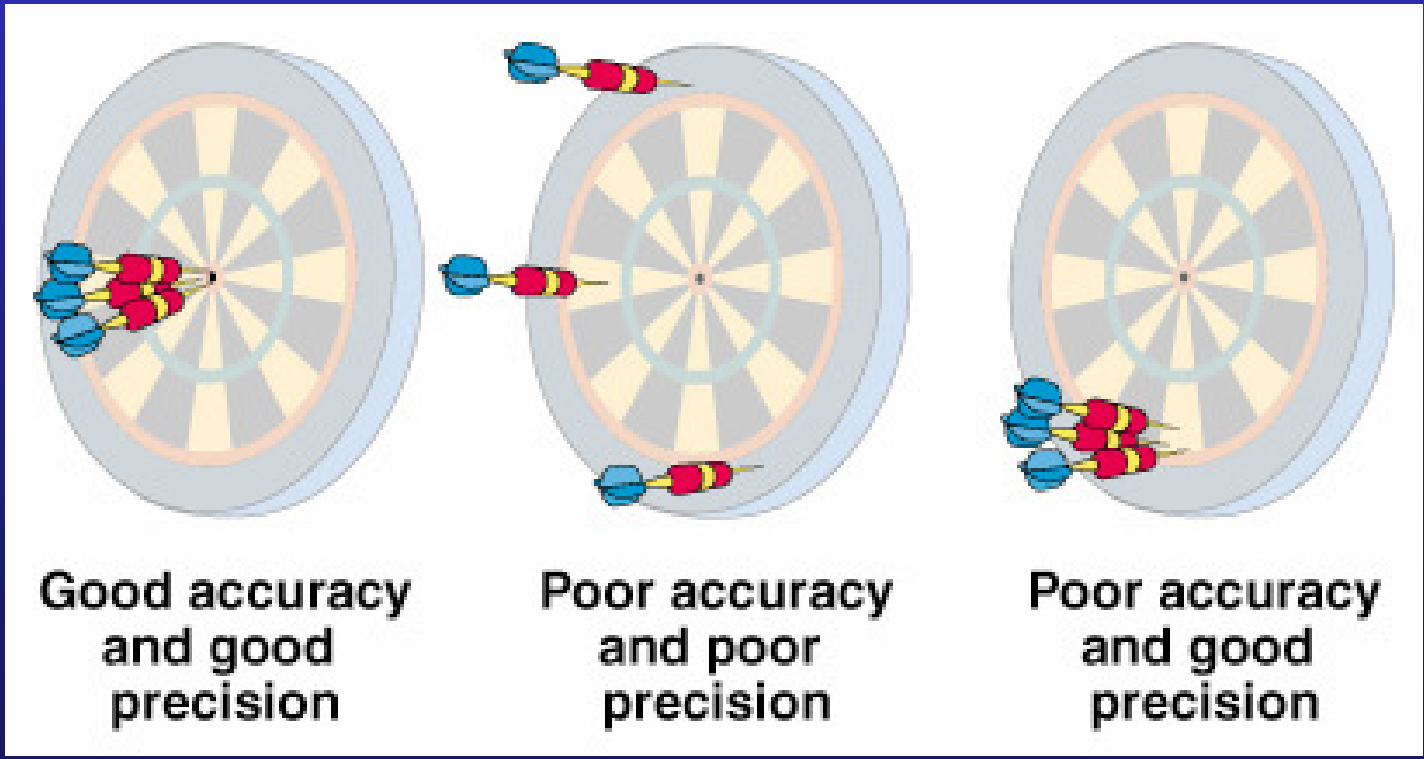
Theory
a conceptual formulation which provides a rational explanation or framework for numerous related observations (ex. global warming due to greenhouse effect)

Scientific Law
a basic underlying principle that matter, energy, & certain other phenomena apparently always act (or react) in a predictable manner (ex. the law of gravity)

Accuracy vs. Precision

Accuracy: extent to which a measurement agrees with the accepted or correct value

Precision: measure of reproducibility



Types of Reasoning

Deductive reasoning: using logic to arrive at a specific conclusion based on a generalization or premise; goes from general to specific.

•http://thepoetsgarret.com/2009Uploads/eagle.jpg

All birds have feathers.

Eagles are birds.

All eagles have feathers.

Types of Reasoning

Inductive reasoning: using observations and facts to arrive at generalizations or hypotheses; goes from specific to general

•http://newzar.files.wordpress.com/2008/10/co2_emissions_main.jpg

CO2 is a heat-trapping gas.

Human activities release CO2 in the atmosphere.

CO2 from human activities is a cause of global climate change.

Moral of the Story:
Use Caution when Reasoning…

•http://3.bp.blogspot.com/_Tq8oPLja_2A/TBzcs0_I_4I/AAAAAAAAAOA/hslf-yOqZ6c/s1600/global-warming2.jpg

Frontier Science vs. Consensus Science

Frontier science: preliminary scientific data, hypotheses, and models that have not been widely tested and accepted; very unreliable aspect of science.

•http://www.stbenedictscollege.co.uk/uploads/assets/national_newspapers_montage.jpg

Frontier Science vs. Consensus Science

Consensus science: scientific data, models, theories, and laws that are widely accepted; very reliable aspect of science.

•http://apps.lib.whu.edu.cn/12/test/farm/school/courses.files/Undergrad.files/journals.jpe

2. Systems

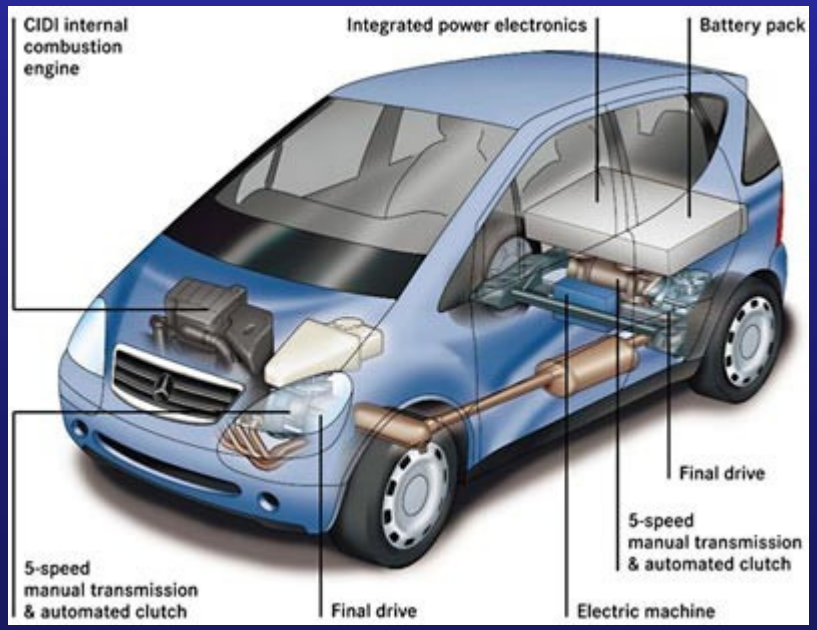
System: **a set of components that function & interact in some regular or predictable manner**

- **structure — the organization of system components**
- **function — what the system does**

Examples of Systems

Circulatory System — natural system (components: heart, arteries, veins, capillaries, & blood) that moves blood through body (function: transport of oxygen, carbon dioxide, & nutrients)

•http://www.buzzle.com/img/articleImages/321356-4662-11.jpg



•http://www.glumac.com/images/newsletter/hybrid_car.jpg

Automobile — human–made system (components: engine, body, brakes, wheels, etc.) that serves to move people & objects (function: transportation)

Using Models to Understand Systems

Models are valuable as approximate representations or simulations of real systems to help find out which ideas or hypotheses work.

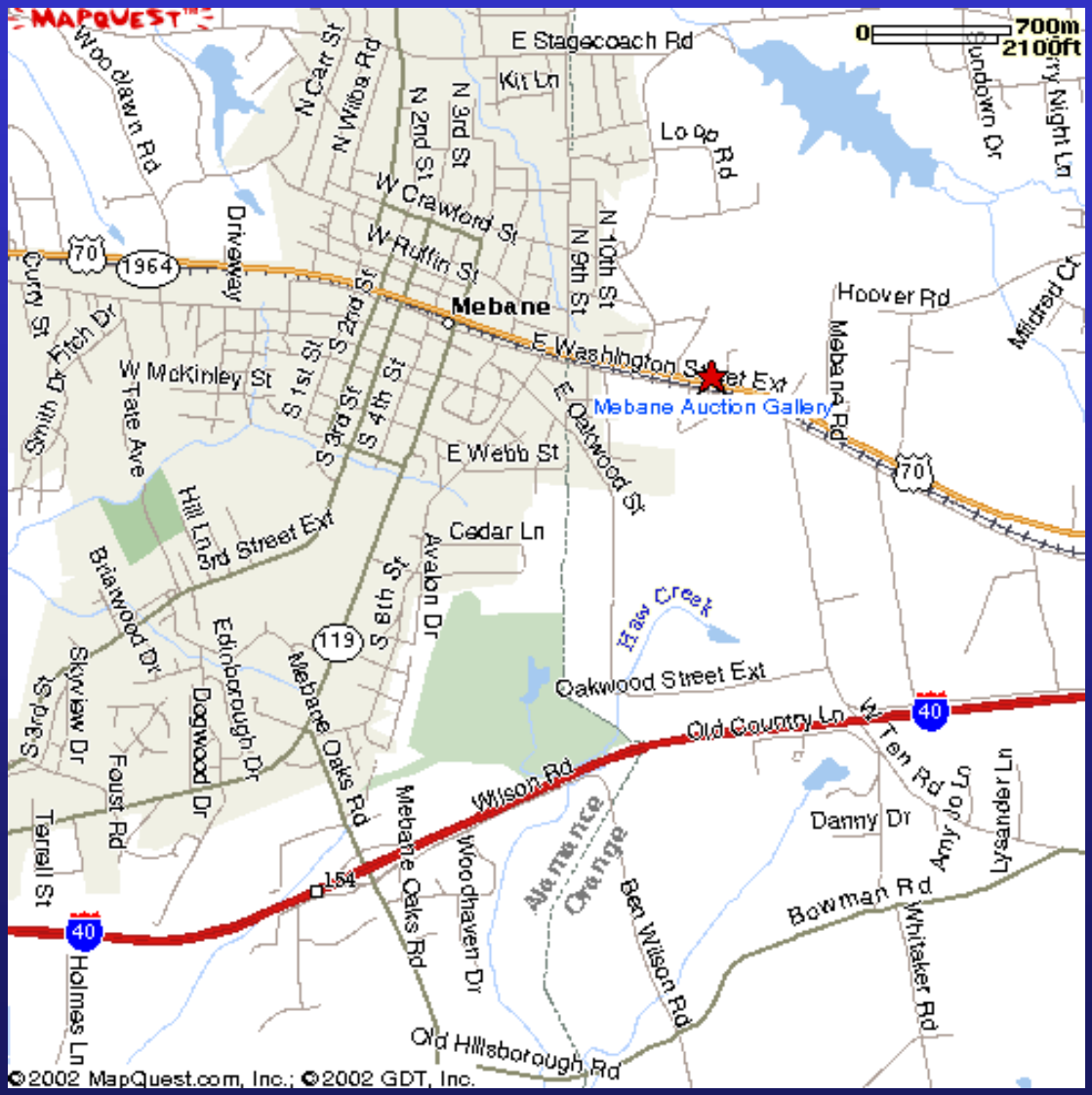
- **Mental Models** – guide our perceptions and help us make predictions

•http://www.womansday.com/var/ezflow_site/storage/images/media/images/06-wd0909-optical-illusions/719368-1-eng-US/06-wd0909-Optical-Illusions.jpg

- **Physical Models** – touchable 3-D models that closely represent an object or system

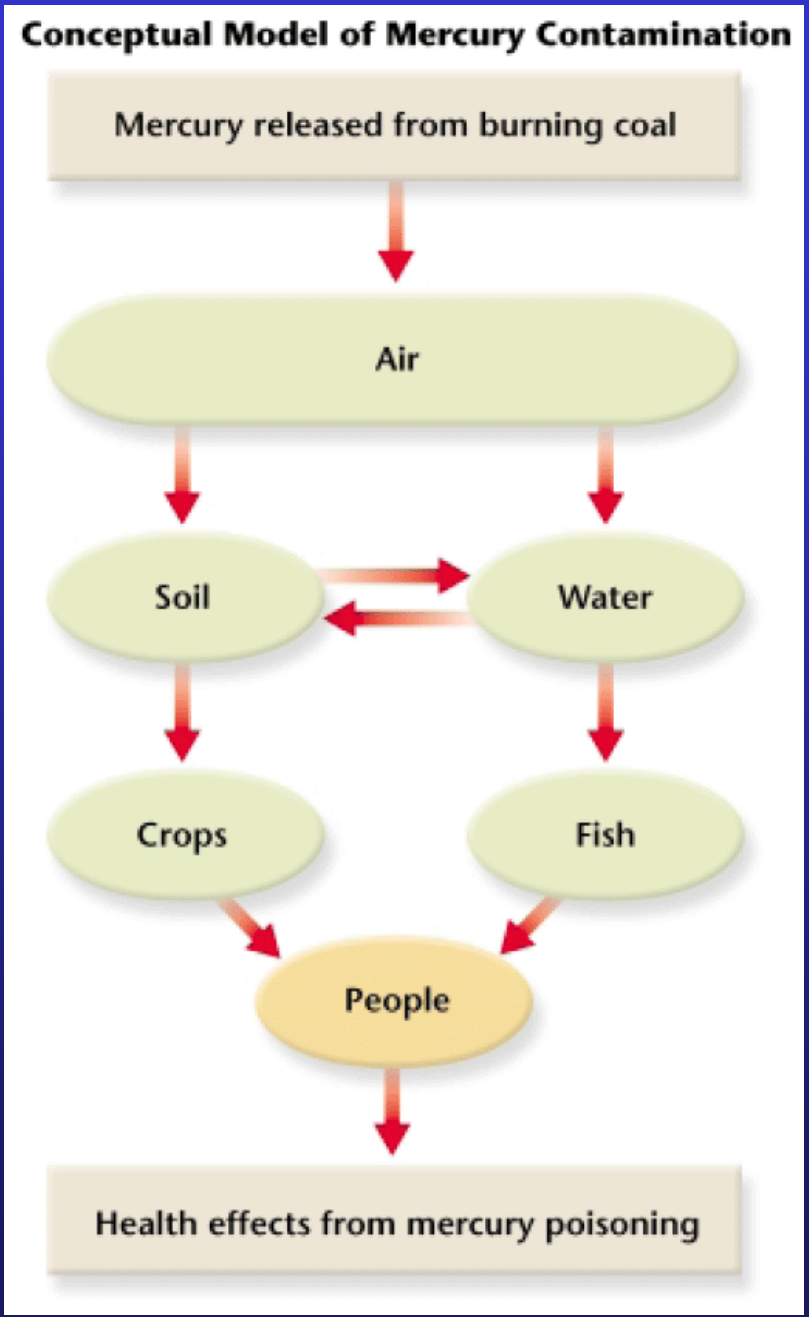
•http://www.cgeglobes.co.uk/images/Atmos%20Blue%20B2%20unlit.jpg

- **Graphical Models** – illustrations which show a representation of an object or system



•http://www.mebaneauction.com/auctionmap.gif

- **Conceptual Models** – verbal or graphical explanation of how a system works or is organized



Arms, Karen. Environmental Science. Holt, 2008.

- **Mathematical Models**
  - One or more equations that represent the way a system or process works
  - Useful in cases with many variables
  - Only as good as the data that went into them

•http://www.digtriad.com/news/most_popular/article.aspx?storyid=157727&provider=top

Inputs, Throughputs, & Outputs

matter, energy, & information flow in (input), through (throughput), & out (output) of a system

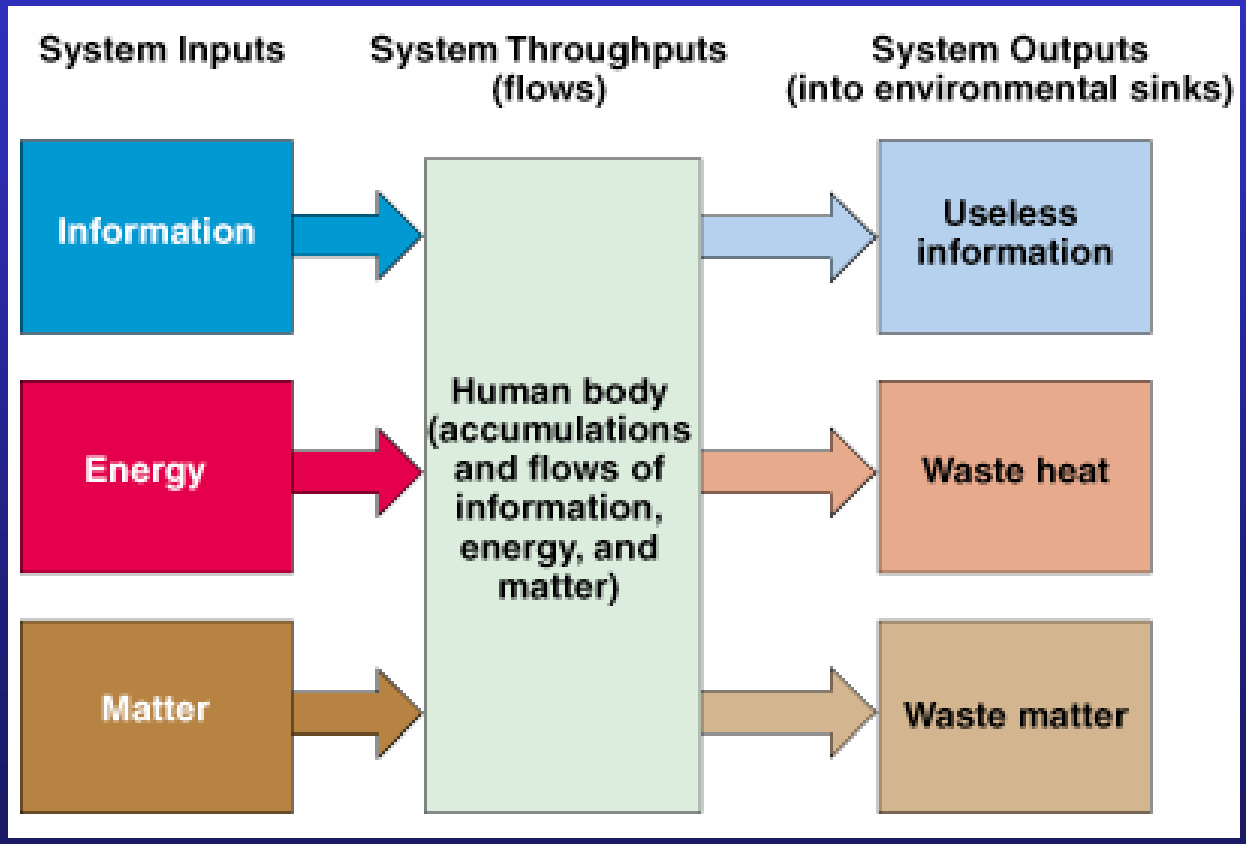


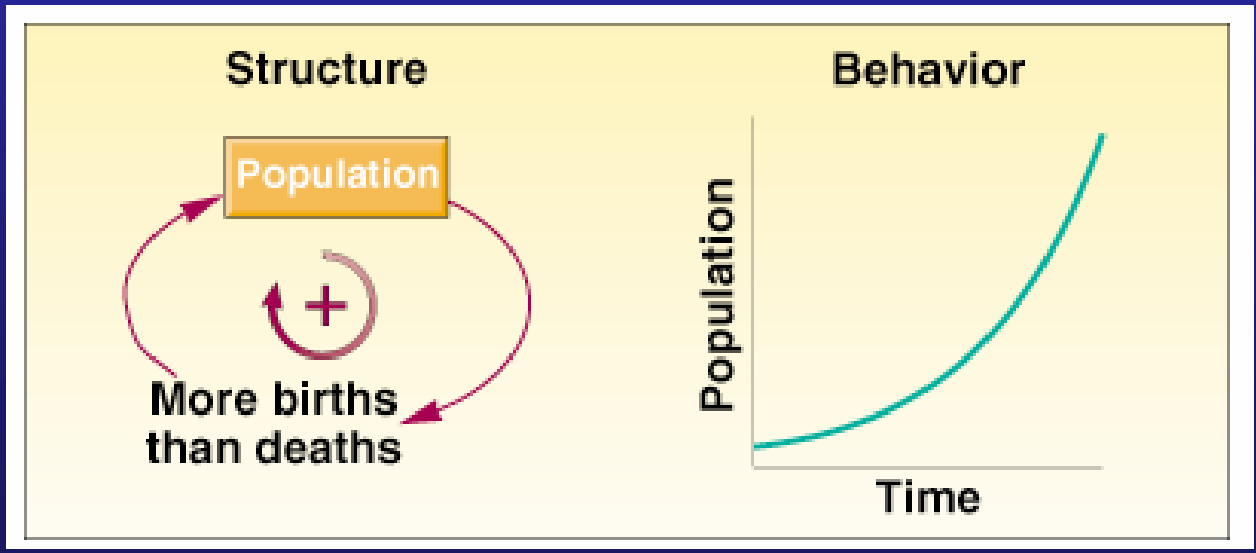
Fig. 2–6

Feedback Loops

Feedback Loop: a relationship in which a change in one part of a system influences another part of the system in a way that either reinforces or slows the original change.

- **Positive Feedback Loop**: a change in a certain direction within a system causes more change in that same direction; ultimately unstable

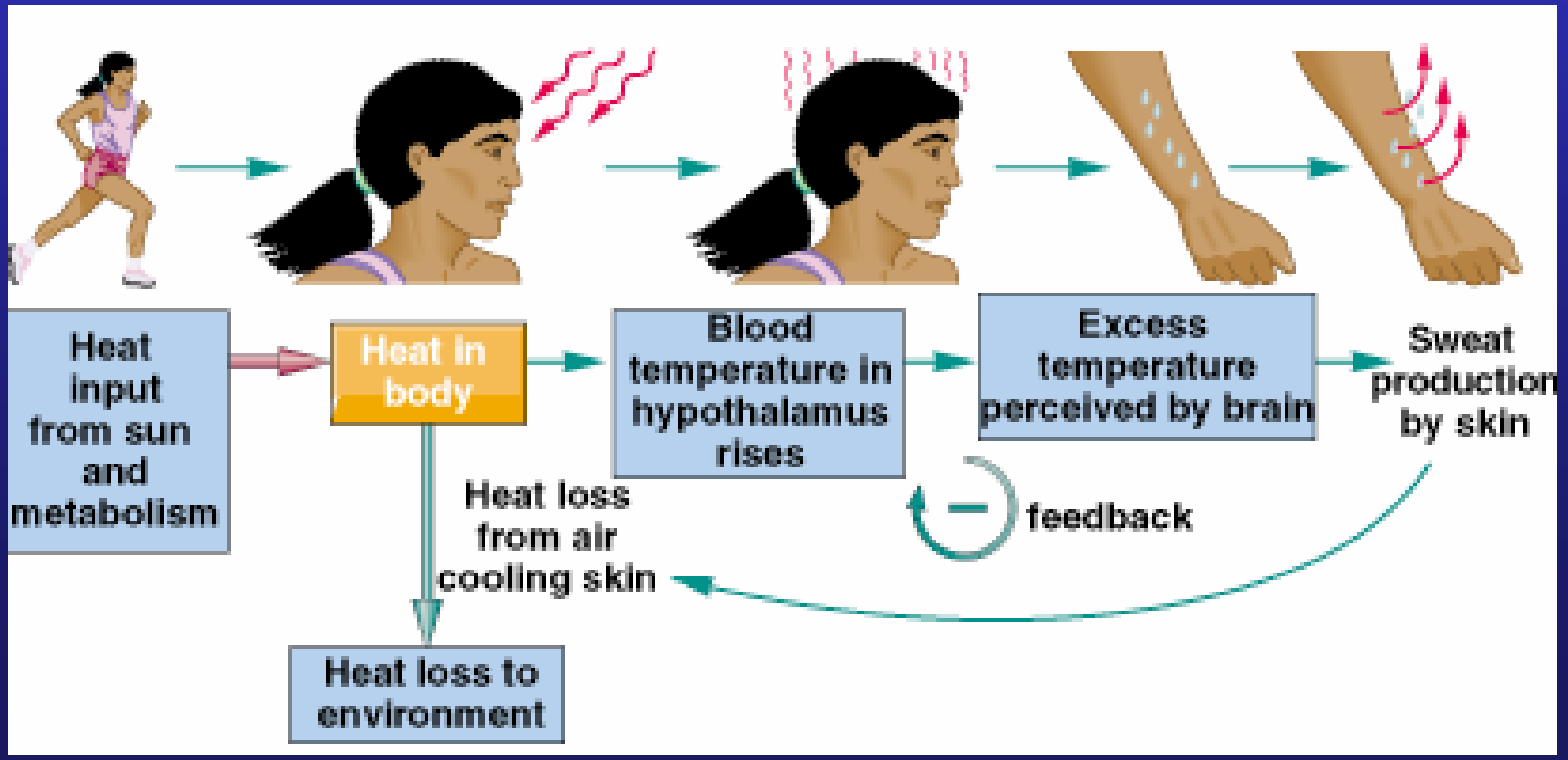
Example: exponential population growth involves a positive feedback loop in which more individuals lead to increased numbers of births.



Feedback Loops

• **Negative Feedback Loop**: a change in a certain direction within a system causes lessening of change in that same direction; ultimately stable.

Example: temperature regulation in humans involves a negative feedback loop in which increased temperature leads to decrease in temperature by sweating; how we maintain **homeostasis**

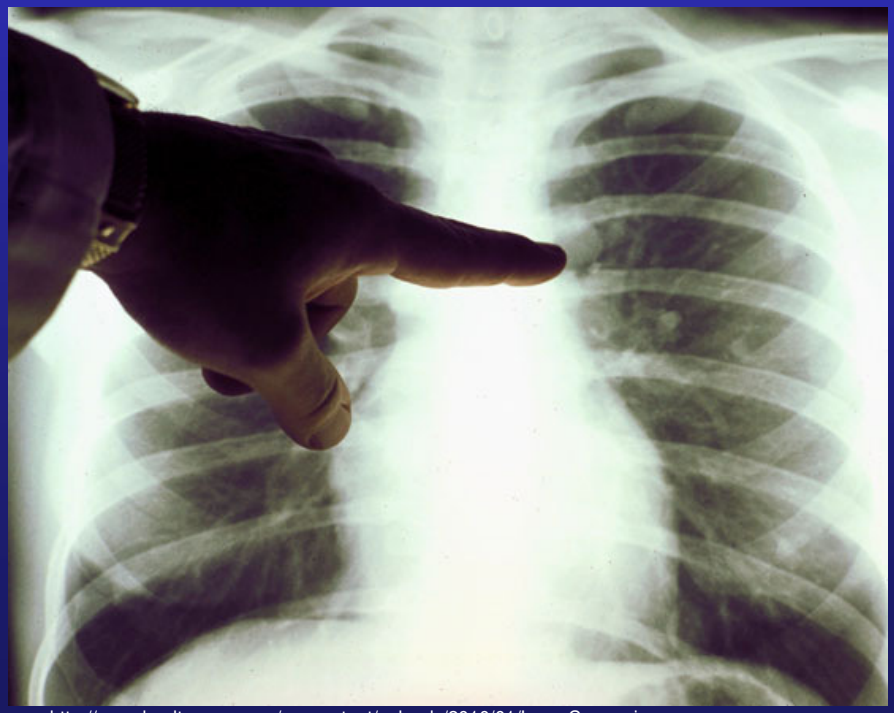


Behaviors of Complex Systems

Some Important Behaviors:

- **Time lags** result when a change in a system leads to other changes after a delay, e.g., lung cancer after 20–30 years of smoking, global warming after decades of carbon dioxide emission.

•http://www.ui-ceo.org/wp-content/uploads/2010/12/smoker-life-insurance-quote.jpg



•http://www.healtynews.com/wp-content/uploads/2010/01/Lung-Cancer.jpg

Behaviors of Complex Systems

- **Resistance to change** is often seen in systems with negative feedbacks that are designed to maintain the system; biological, chemical, and physical components can shift to absorb and cancel much of the change

•GOOD: Acid precipitation has less of an impact on areas with natural buffers

•http://web4.msue.msu.edu/mnfi/images/communities/3381.jpg

•BAD: many economic & political systems resist environmental initiatives like pollution penalties

•http://itcouldbesweet.files.wordpress.com/2007/10/factory2saved4web2.jpg

Behaviors of Complex Systems

- **Synergy** results when two or more processes interact to that the combined effect is more than the sum of their separate effects, e.g., team efforts using multiple talents.

Pests and Diseases of Potato

Colorado potato beetle

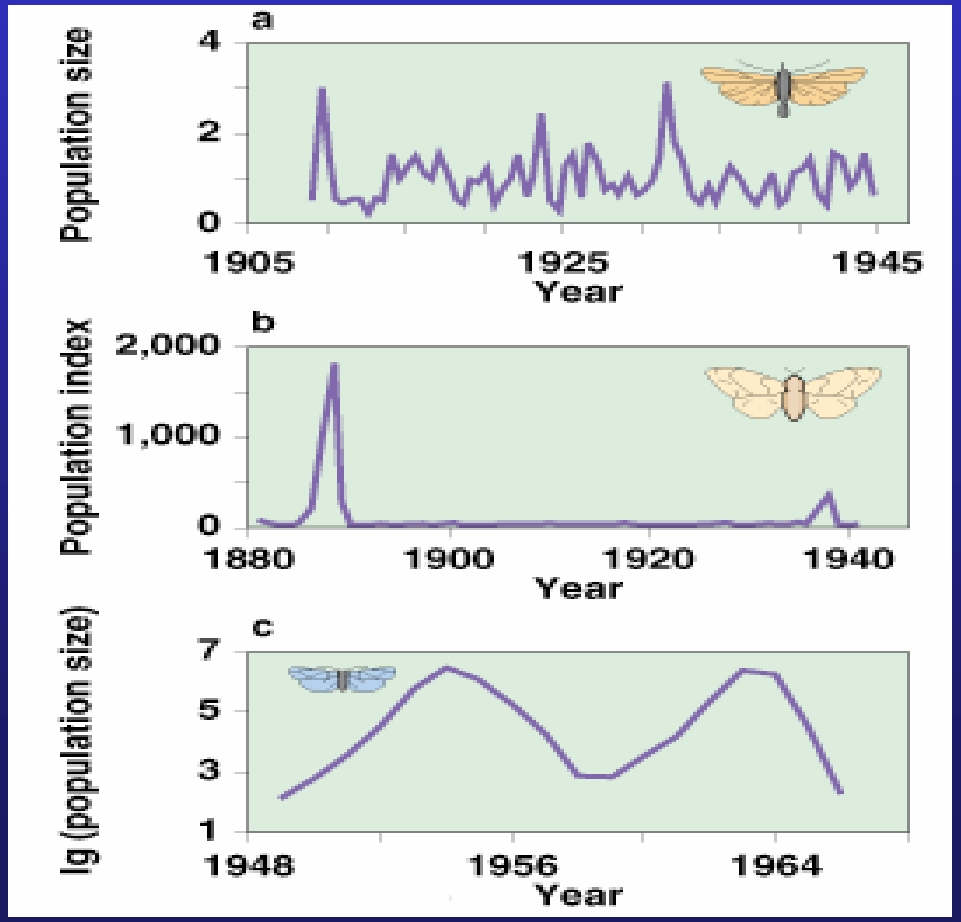
Late blight

•http://ocw.tufts.edu/data/40/434509/434514_xlarge.jpg

Behaviors of Complex Systems

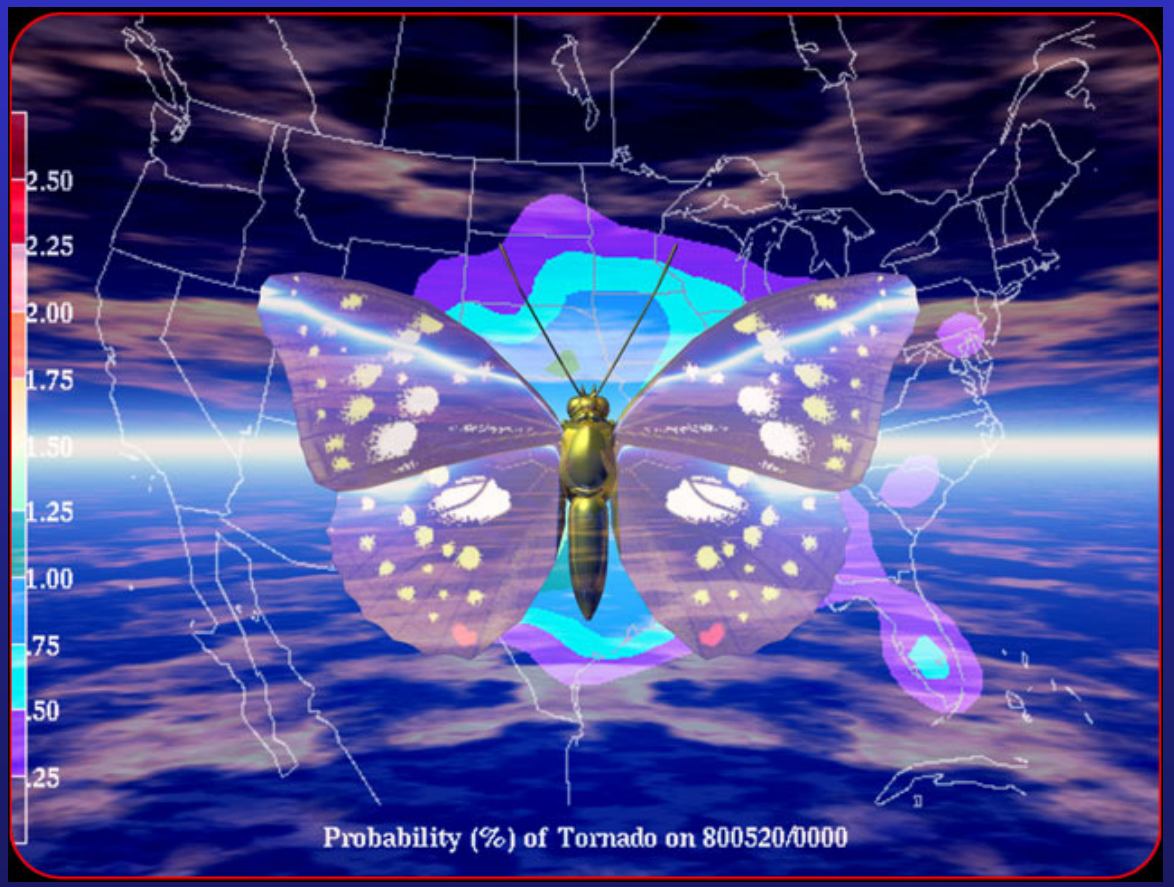
- **Chaos** results when noisy or unpredictable behavior is generated from within the system itself, e.g., waves in the ocean, day–to–day variation in weather.

Example: Population dynamics of three moth species display very different patterns. It is not known whether the observed patterns are caused by chaotic behavior or orderly behavior not yet sufficiently understood.



Behavior of Complex Systems

- Chaotic systems can be extremely sensitive to even small disturbances
- Sometimes called the **Butterfly Effect** which alludes to the possibility that a single butterfly flapping its wings can cause minute changes in the movement of air that can eventually initiate a cascade of highly unpredictable changes in the env't



•http://www.rsc.org/chemsoc/timeline/graphic/1972_be.jpg

Designing a Controlled Experiment

- **Independent Variable** – one factor of interest that is being tested
- **Dependent Variable** – what is changing because of the independent variable
- **Experimental Group** – group that receives the experimental treatment/is exposed to the IV
- **Control Group** - group that doesn't receive the experimental treatment/is not exposed to the IV
- **Constants** – all other factors that remain the same between the experimental and control groups

Designing a Controlled Experiment

•http://www.bio.mq.edu.au/dept/centres/piccel/images/rescaledIsno.jpg

Salinization: How Much is Too Much?

•http://www.geography.hunter.cuny.edu/~tbw/ncc/chapter5.nat.res/irrigation.salinization.hot.climate.jpg